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EVALUATION OF SOIL MECHANICS LABORATORY EQUIPMENT. REPORT 12. MODIFIED BERKELEY PNEUMATIC TAMPER FOR COMPACTING TEST SPECIMENS OF COHESIVE SOILS

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Army Engineer Waterways Experiment Station
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EVALUATION OF SOIL MECHANICS LABORATORY EQUIPMENT

Report 12

MODIFIED BERKELEY PNEUMATIC TAMPER FOR COMPACTING TEST SPECIMENS OF COHESIVE SOILS

by

B. N. MacIver, R. T. Donaghe

Details of illustrations in this document may be better studied on microfiche.

June 1971

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Foreword

The U. S. Army Engineer Waterways Experiment Station (WES) is conducting a continuing evaluation of new items of soil mechanics laboratory equipment and investigations of laboratory testing procedures for the Office, Chief of Engineers (OCE), under Item ES 516 of the Engineering Studies program. The study was initially approved by OCE in March 1957 and broadened in scope to include testing procedures in October 1964. Parts of the study since 1967 have concerned the methods of preparing test specimens of compacted cohesive soils and the procedures for performing triaxial compression tests on specimens of this type. It was during these recent parts of ES 516 that the equipment described in this report became needed and, subsequently, was developed.

The pneumatic tampers were designed and detailed by Mr. B. N. MacIver, former Chief, Laboratory Research Section, Soils Division, WES, based on the concept developed at the University of California at Berkeley, California. Parts for the original pneumatic tamper were fabricated by Mr. D. J. Harmon, Shops Branch, Construction Services Division, WES, while those for the modified tamper were fabricated by Mr. G. R. Hall. Calibration and modification of the tampers were performed by Mr. R. T. Donaghe, Laboratory Research Section, under the immediate supervision of Mr. MacIver and under the general supervision of Mr. J. R. Compton, Chief, Embankment and Foundation Branch, and Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, respectively, Soils Division. This report was prepared by Messrs. MacIver and Donaghe.

COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE, were Directors of WES during the development of the equipment and the preparation of this report. Mr. F. R. Brown was Technical Director.

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Conversion Factors, British to Metric Units of Measurement

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
square inches	6.4516	square centimeters
pounds	0.4536	kilograms
pounds per square inch	0.0703	kilograms per square centimeter
pounds per cubic foot	16.0185	kilograms per cubic meter

Summary

Difficulties have been encountered in reproducing sufficiently similar dry unit weights (within $\pm$ 0.3 pcf) in 1.4-in.-diam triaxial test specimens of cohesive soil compacted using the spring-loaded Harvard miniature compactor. In an effort to alleviate these difficulties, a tamper was made which maintained a constant force on the compacting foot by air pressure acting on a rolling diaphragm. It is designated as the "modified Berkeley pneumatic tamper," since it is a modification of a tamper designed by Mr. C. K. Chan of the University of California, Berkeley, Calif. Calibration and operation showed the pneumatic tamper to be a significant improvement over the spring-loaded tamper. The tamper permits rapid and precise adjustment of the tamping force, with assurance that the tamping force actually applied to the soil is the same for each tamp even when used by different operators. It is believed that laboratories preparing test specimens of cohesive soils by kneading compaction can improve the quality and efficiency of this activity by using a pneumatic tamper.

EVALUATION OF SOIL MECHANICS LABORATORY EQUIPMENT

MODIFIED BERKELEY PNEUMATIC TAMPER FOR COMPACTING TEST SPECIMENS OF COHESIVE SOILS

Background

1. The Harvard compaction test was developed in 1949 by Mr. S. D. Wilson under the guidance of Professor A. Casagrande of Harvard University to obtain moisture-density relationships for cohesive soils that more closely duplicate those from field compaction tests than do those obtained from Proctor tests.[1,2] To perform the test, Mr. Wilson designed the Harvard miniature compaction device consisting of (a) a mold for a specimen 1.312 in.* in diameter and 2.816 in. in height and (b) a hand tamper with a 1/2-in.-diam foot loaded by a spring of either 20- or 40-lb initial force. The tamper, shown in fig. 1, is held vertically by both hands and the foot is pressed against the soil in the mold until a slight relative movement between the handle and the foot indicates that the full force of the spring is acting on the foot. Soil is placed in the mold in layers and each layer is covered by a predetermined number of quick tamps. The density of the specimen is controlled by (a) the number of layers, (b) the number of tamps per layer, and (c) the force per tamp. Since the specimen has a height-to-diameter ratio of 2.14, it can be used for unconfined and triaxial compression tests. Triaxial testing of compacted cohesive soils at Harvard University utilized 1.312-in.-diam specimens until 1963 when equipment was changed to accept the standard 1.40-in.-diam specimen 3.50 in. in height.[3] At that time, a larger, split mold was made.

2. While the Harvard compaction test has been used occasionally to define moisture-density relationships for soils, it has not replaced the Proctor test for compaction control purposes. However, the Harvard miniature compaction device, with a 1.40-in.-diam mold, is widely used to prepare triaxial test specimens of cohesive soils; it has become a standard, commercially available item of laboratory equipment.

3. Considerable research on the physical properties of soils by

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* A table of factors for converting British units of measurement to metric units is presented on page ix.

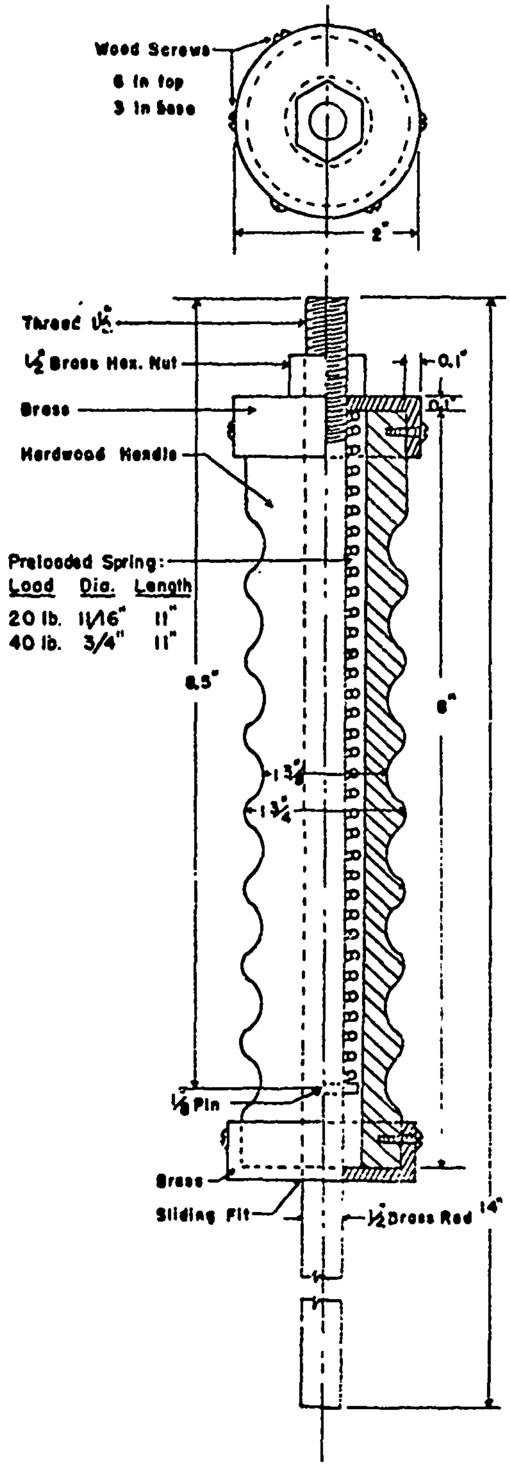
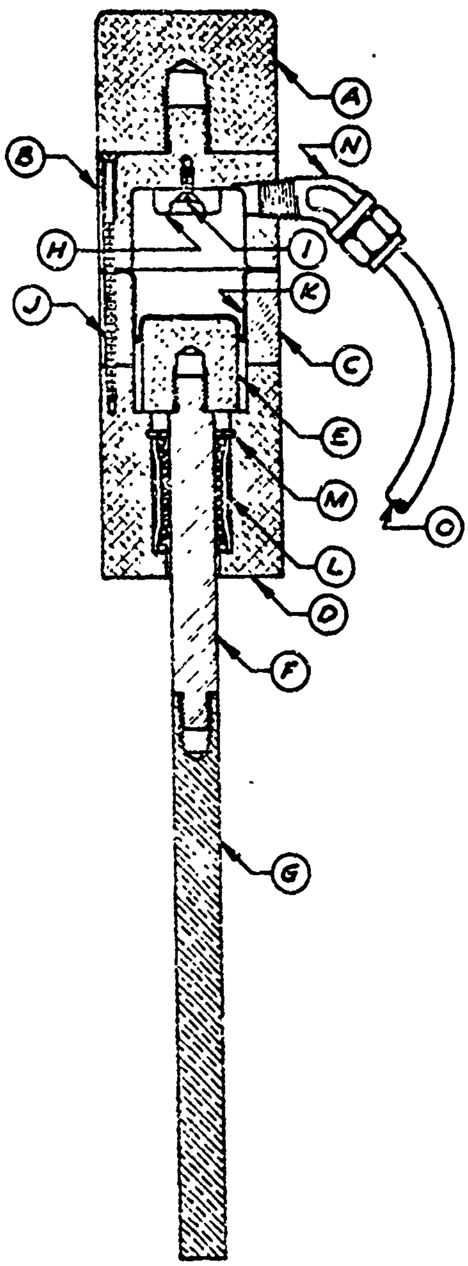


Fig. 1. Section showing details of Harvard miniature compactor

the University of California at Berkeley has involved triaxial testing of compacted cohesive soils. The spring-loaded Harvard miniature compactor was used until 1962 to prepare 1.40-in.-diam specimens.[4] In 1962, Mr. C. K. Chan, Research Engineer at the University of California's Richmond Field Station (where the University's principal laboratory facilities for soil mechanics are located), designed a tamper similar in appearance and operation to the Harvard miniature compactor except that the foot was loaded by air pressure rather than spring force. This tamper, shown in fig. 2, contains a piston, sealed by a rolling diaphragm, which is connected to the foot by a shaft operating in a linear ball bushing. The effective area of the diaphragm is about 1 sq in., so 1 psi of air pressure produces about 1 lb of tamping force. The upper part of the body can be unscrewed to expose a threaded boss; this boss permits the tamper to be fastened to an arbor press for mechanical operation. To give credit to the source of this development, which has never been published, the tamper is identified herein as the "Berkeley pneumatic tamper."

4. In 1967, the U. S. Army Engineer Waterways Experiment Station (WES) started an investigation under ES 516 of the effects of strain rate on the results of unconsolidated-undrained (R) triaxial tests. The investigation began by first testing specimens compacted of Vicksburg silty clay (CL standard soil sample) and, later, Vicksburg buckshot clay (CH standard soil sample). Specimens were 1.40 in. in diameter and 3.0 in. in height. A Harvard miniature compactor fitted with a spring of about 10-lb initial force was used to compact the specimens. Difficulty was encountered in producing specimens sufficiently similar in dry unit weight (within ± 0.3 pcf) for the rate of strain investigations even though the same procedure (number of layers, number of tamps per layer, and force per tamp) was followed. Many CL and CH specimens had to be compacted and discarded before acceptable specimens were obtained. These problems were attributed to the use of the spring-loaded tamper.

5. A pneumatic tamper was made by the WES in mid-1969 essentially in accordance with the original sketch furnished by Mr. Chan in 1964.



Mark	Req'd	Material	Description
A	1	Aluminum	Handle
B	1	Aluminum	Base
C	1	Lucite	Cylinder
D	1	Aluminum	Head
E	1	Aluminum	Piston
F	1	Hardened Steel	Shaft
G	1	Brass	Compac[illegible]
H	1	Rubber	Bumper Block
I	1	Steel	No. 6-32 NC - 1/4 Flat Head Screw
J	3	Steel	No. 4-48NF-2 x 2 1/2 Flat Head Screw
K	1	Elastomer	Rolling Diaphragm, Bellofram Part No. 4-125-100-C
L	1	Steel	Linear Ball Bushing, Thomson Part No. A-81420
M	1	Steel	Retaining Ring, Truarc Ring Size No. N5000-87
N	1	Brass	Flex 45° Male Elbow, Imperial Catalog No. 94-FL, 1/4 Tube by 1/8 NPT
O	1	Tygon	Line To Pressure Source, 1/4 Tube

SCALE : HALF SIZE

Fig. 2. Section showing details of original Berkeley pneumatic tamper

The advantages of the tamper were immediately apparent, though calibration of the instrument produced force-displacement relationships that were not as linear as had been expected. During the latter part of 1969, several slight modifications were made to the tamper in an effort to improve the force-displacement relationship.

6. First, the diameters of the piston and the cylinder were adjusted in the WES version to those recommended by the manufacturer of the rolling diaphragm (stated by manufacturer to have an effective area of 1.048 sq in.). A slight improvement resulted from adding a curved-lip retainer plate to the piston as recommended by the diaphragm manufacturer. The height of the piston was increased so that the diaphragm was closer to a position aligned with the flange at the start of the stroke. Ball bearings were used to separate the piston from the foot to protect the diaphragm from torsional stresses. Finally, a hardened shaft was obtained from the manufacturer of the linear ball bushing. These modifications, collectively, produced a disappointingly small improvement in the calibration, leaving the force-displacement relationship still markedly nonlinear, as is discussed later.

7. One possible source of irregular results with the pneumatic tamper was considered to be binding of the shaft in the single ball bushing under a lateral force. Since the tamper is hand-held, some eccentricity of the force at the end of the long foot would have to be expected, but calibration of the effect of this is not possible. It was believed that this problem could be largely avoided if the shaft were guided by two slightly separated ball bushings, as are commonly used to guide the piston entering a triaxial test chamber.

8. In early 1970, a second pneumatic tamper was made by WES that incorporated all modifications and ideas developed during the work with the original model. This 1970 tamper is designated the "modified Berkeley pneumatic tamper." Its design and operation are described in the following paragraphs.

Description of the Modified Berkeley Pneumatic Tamper

9. The exterior appearance of the modified Berkeley pneumatic tamper is shown in fig. 3, while the internal arrangement is shown in fig. 4. The unit is 16 in. in overall length and weighs about 2.5 lb. The main parts are machined of aluminum, while the piston and the shaft are made of stainless steel. A complete listing of parts and working drawings are presented in Appendix A.

10. The hardened stainless steel shaft supporting the compacting foot is guided by two well spaced linear ball bushings held by retaining rings in a single, reamed hole. Retaining rings also connect the shaft to the stainless steel piston through two deep-groove, radial ball bearings; the thrust capacity of the bearing is much in excess of the maximum force to be applied with the tamper. The necessity for these bearings was proven by a diaphragm damaged by repeated twisting in the original pneumatic tamper.

11. Both above and below the air chamber, which is fixed in diameter by the requirements of the diaphragm, the body is extended a sufficient length to provide room for the largest hand. The diameter of the extensions was chosen to be the optimum for firm gripping by hands of all sizes. Knurling is provided on both extensions to enhance the gripping power.

12. A threaded boss, exposed by removal of the handle, is provided at the top for possible mechanization of the tamping action. However, the boss was made to accept a tube fitting so that the air pressure line could enter through the end of the handle. Soft, flexible, transparent polyvinyl chloride (Tygon) tubing has been found satisfactory for the air line. The burst pressure of the 1/4-in.-OD Tygon tubing used is almost 200 psi, which is well above the maximum working pressure of the tamper.

13. Other sizes and lengths of compacting feet can be used for different types of specimen molds: e.g. a square foot can be used to compact cohesive soil into a square direct shear box. A 0.500-in.-diam foot is used in compacting 1.40-in.-diam triaxial test specimens. A significant

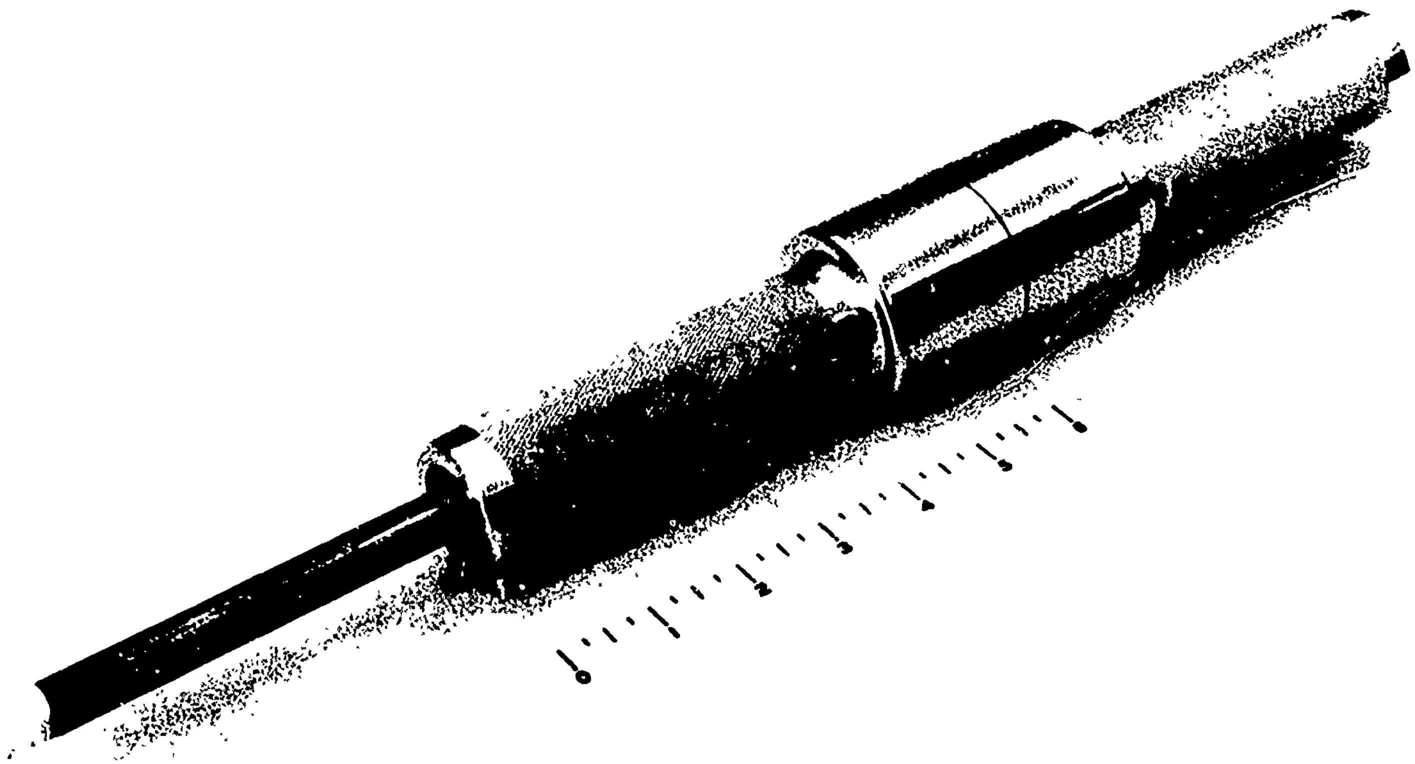


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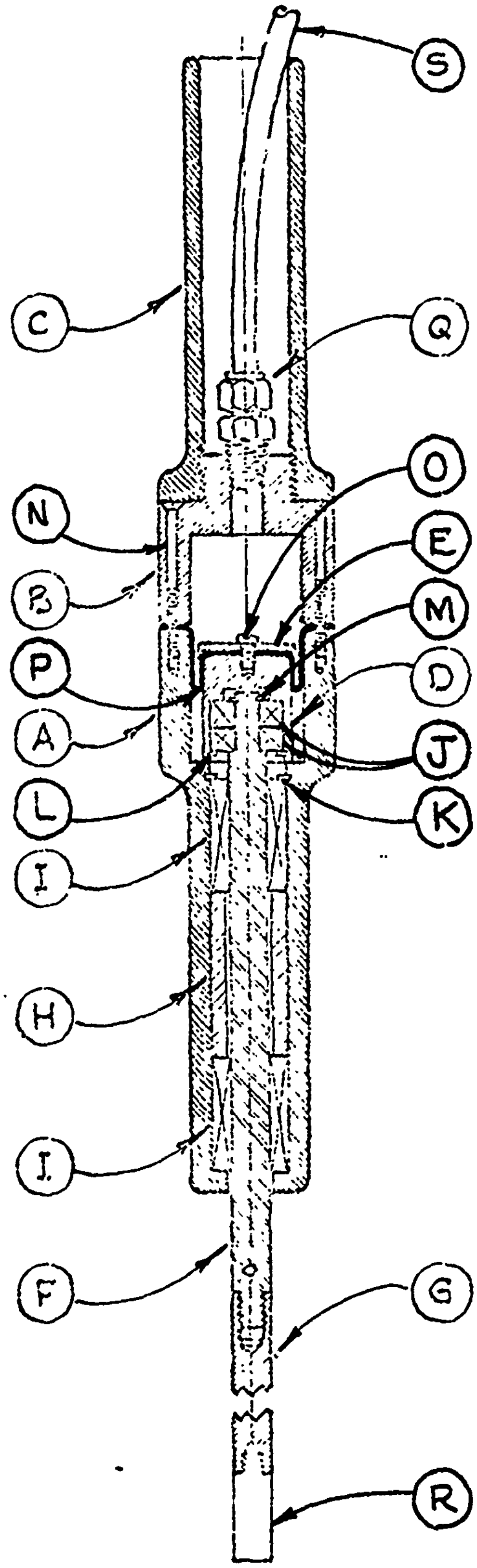
Fig. 3. Modified Berkeley pneumatic tamper



Mark	Req'd	Material	Description
A	1	Aluminum	Body
B	1	Aluminum	Head
C	1	Aluminum	Handle
D	1	Stainless Steel	Piston
E	1	Aluminum	Diaphragm Retaining Plate
F	1	Stainless Steel	Shaft, "60 Case"
G	1	Brass	Extension
H	1	Teflon	Ball Bushing Spacer
I	2		Ball Bushing, Thompson [illegible]
J	2		Ball Bearing, SKF No. [illegible]
K	1		Retaining Ring, Truarc N5000-87
L	1		Retaining Ring, Truarc N5000-86
M	1		Retaining Ring, Truarc [illegible]-27
N	4	Brass	Flat Head Screw, No. 4-[illegible]NF-[illegible]
O	1	Stainless Steel	Fillister Hd. Screw, No. 6-[illegible]
P	1		Rolling Diaphragm, Bellofram Part No. 4-125-100
Q	1	Brass	Male Connector, Imperial No. [illegible] 1/4 Tube To [illegible] NPT
R	1	Teflon	Compacting Foot
S	1	Tygon	Line To Pressure Source, [illegible] Tube

SCALE : HALF SIZE

Fig. 4. Section showing details of modified Berkeley pneumatic tamper

improvement in the operation of the tamper was the addition of a Teflon tip to the 0.50-in.-diam foot. When a metal foot is used, most cohesive soils will form a dense lump on the tamping face, so that compaction is actually performed by a bullet-shaped foot rather than a flat-faced one. Soils encountered so far do not tend to adhere to the Teflon, and the actual face of the foot is always a plane. The Teflon tip is sufficiently long to permit the face to be remachined several times to compensate for rounding of the edge.

14. Air pressure control is provided by a tank equipped with a Bourdon tube gage, a supply valve, and a vent valve. Air is supplied to this tank from a second, high-pressure tank.

Calibration of the Modified Berkeley Pneumatic Tamper

15. For convenience in establishing the force-pressure and force-displacement relationships, the tamper was placed, with its foot pointed upward, on the moving lower platen of a controlled-strain triaxial loading machine. The tip of the foot bore against the button of an electrical load cell. The body of the tamper was moved upward and downward at a constant rate of strain (about 0.040 in. per min) while the displacement of the foot was measured with a dial indicator and the force acting on the foot was measured by the load cell through a precision millivoltmeter. In this position, the force acting on the tip of the foot is not equal to the product of the air pressure and the effective area of the rolling diaphragm; rather, it is equal to the pressure-area product minus the dead weight of the moving parts (foot, shaft, piston, etc.). However, when the tamper is being used to compact a specimen, the foot is pointed downward; in this position, the force acting on the tip of the foot (that is, applied to the soil) is equal to the pressure-area product plus the dead weight of the moving parts. Thus, the effective tamping force is the sum of the force measured by the load cell and twice the weight of the moving parts. This correction has been applied to all of the data reported herein.

16. In fig. 5 are shown two typical force-displacement relationships

for the modified Berkeley pneumatic tamper. The curvature of each relationship, especially at the start of the loading phase, and the hysteresis in each cannot yet be explained, though it is believed that these reflect characteristics inherent in a rolling diaphragm. The value indicated for "friction" is not believed to be a mechanical friction developed by the shaft operating through the ball bushings. Rather, these effects may be caused by the force needed to roll the diaphragm from the wall of the body to the wall of the piston and then vice versa. The neutral position of the diaphragm, when the web on top of the piston is at the same level as the flange clamped to the body, is reached at a shaft displacement of 5/16 in., and the curve appears essentially horizontal at this displacement. However, changing the distance from the start of displacement to the neutral position did not reduce the force increase (about 0.4 lb) during this distance, but only the rate at which the force increased.

17. Of particular interest in fig. 5 is that the nonlinearity and hysteresis of the force-displacement relationship is the same for the two different pressures. This is considered further substantiation that these force changes are caused by the rolling of the diaphragm.

18. From observations of the use of the tamper to compact many specimens, it was decided that the most practical displacement to allow during operation was from 1/4 to 3/8 in. Thus, the neutral position of the diaphragm was located at the average of the limiting operating displacements (5/16 in.), and the relationship between tamping force and air pressures, shown in fig. 6. was based on this average displacement. It was found that an operator could easily restrict the displacement to the above limits.

19. Displacement of the shaft changes the volume of the air chamber and, therefore, produces a flow of air through the tubing to the reservoir tank. To determine whether, during the compaction of a specimen by quick tamps, the flow of air from the chamber might be sufficiently restricted to cause a transient rise in pressure acting on the diaphragm, the tamper was operated in the normal manner with the foot bearing on the button of an electrical load cell monitored by a high-speed strip chart recorder.

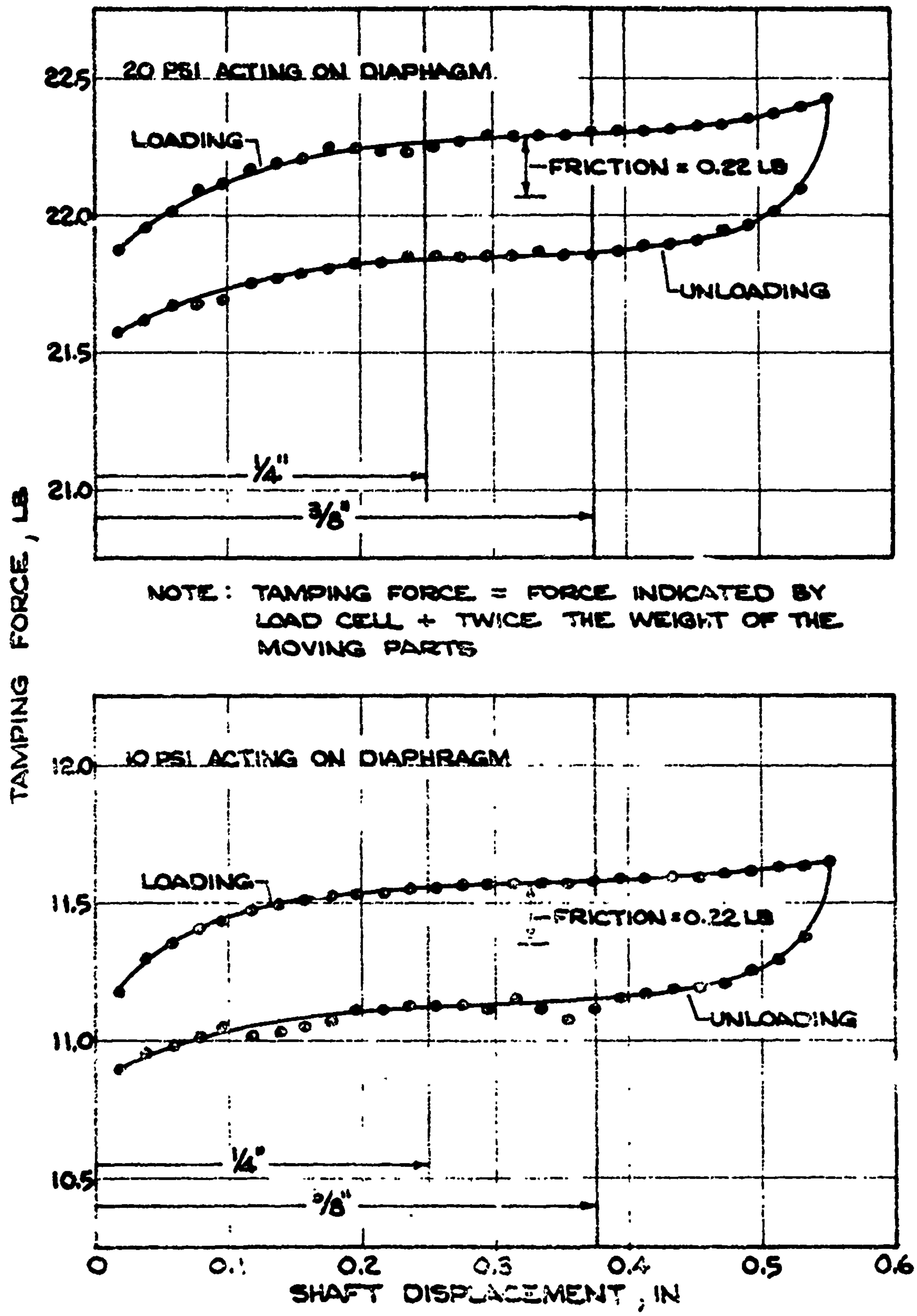


Fig. 5. Force-displacement relationships for the tamper at two different air pressures

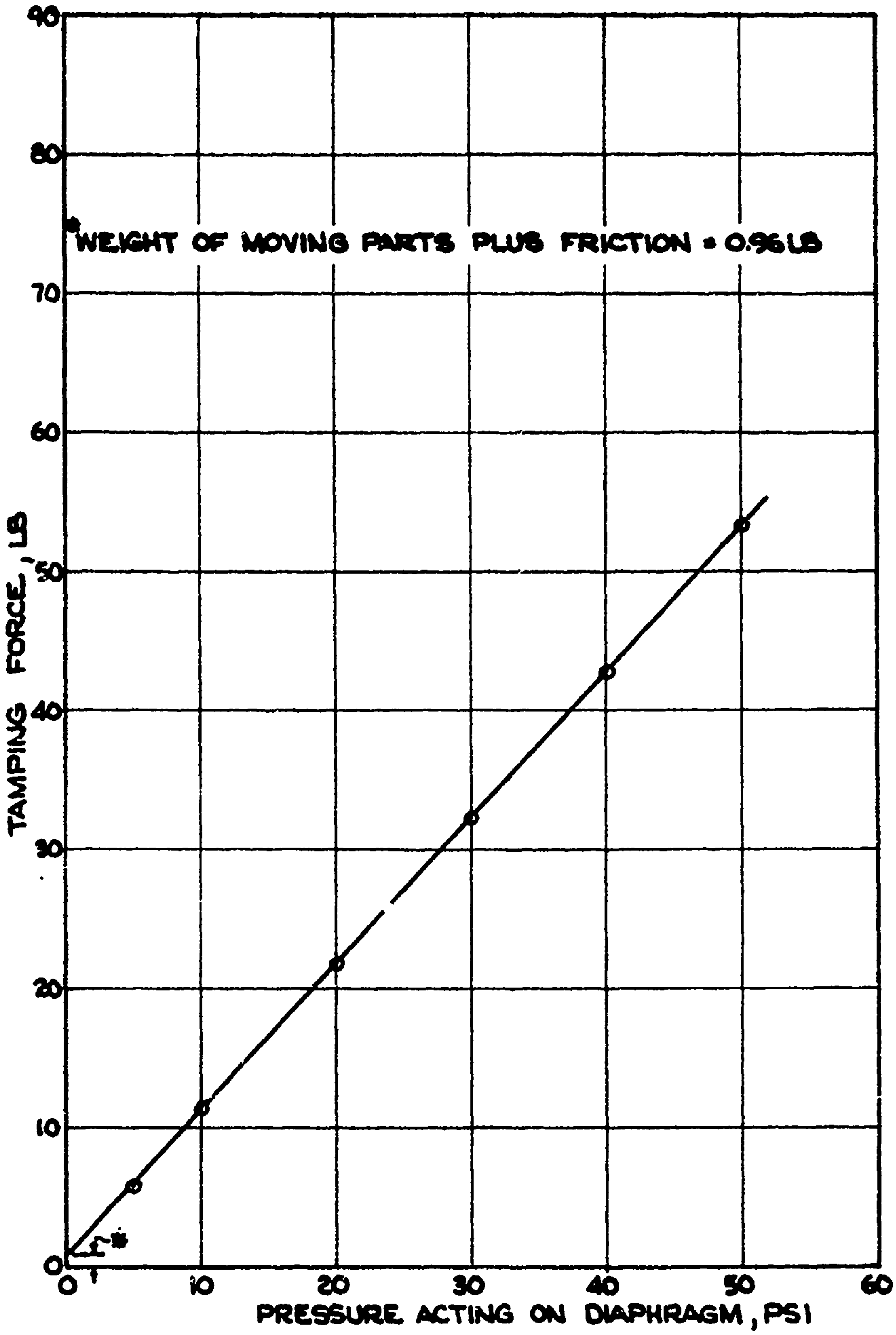


Fig. 6. Relationship between tamping force and air pressure corresponding to a shaft displacement of 5/16 in.

Even at tamping rates as high as two tamps per second, there was no increase in the tamping force above that measured in a static application.

20. One advantage of the pneumatic tamper is revealed in fig. 7 by a comparison of force-displacement relationships with those obtained from a Harvard miniature compactor by similar procedures. When the displacement of the pneumatic tamper is kept between 1/4 and 3/8 in. (see para. 18), the same force was applied with each tamp. Controlling the foot displacement of the Harvard device, however, is more difficult and is critical; with the 20-lb spring, a variation of 1 to 2 lb of force between successive tamps would appear likely even in the hands of an experienced technician. The effect of a variable tamping force can be seen from the relationships between dry unit weight and tamping force for the pneumatic tamper presented in fig. 8. For the CH material, a 1-lb variation in tamping force is equivalent to a variation in dry unit weight of about 2 lb/cu ft.

Operation of the Modified Berkeley Pneumatic Tamper

21. As shown in fig. 9, the pneumatic tamper is operated in the same manner as the Harvard miniature compactor. Typically, the majority of the tamping force is applied with the upper hand, while the lower hand shifts the position of the foot between tamps. To permit correct positioning of the foot and to avoid impact when placing the foot on the soil, a rate of tamping between 1.5 and 2.0 seconds per tamp is used. With each tamp, the shaft is allowed to move into the body a distance between 1/4 and 3/8 in., as mentioned before.

22. The tamping force of the pneumatic tamper can be readily and precisely changed. This is of great advantage in the frequent situation of having to prepare test specimens at a specified water content and dry unit weight of a soil with which the technician is not familiar. With the freedom to adjust the tamping force, the technician can establish standard values of the other two variables, i.e., number of layers and tamps per layer. Limited experience at WES in compacting and testing the CL and CH standard soil samples has led to the use of eight layers for

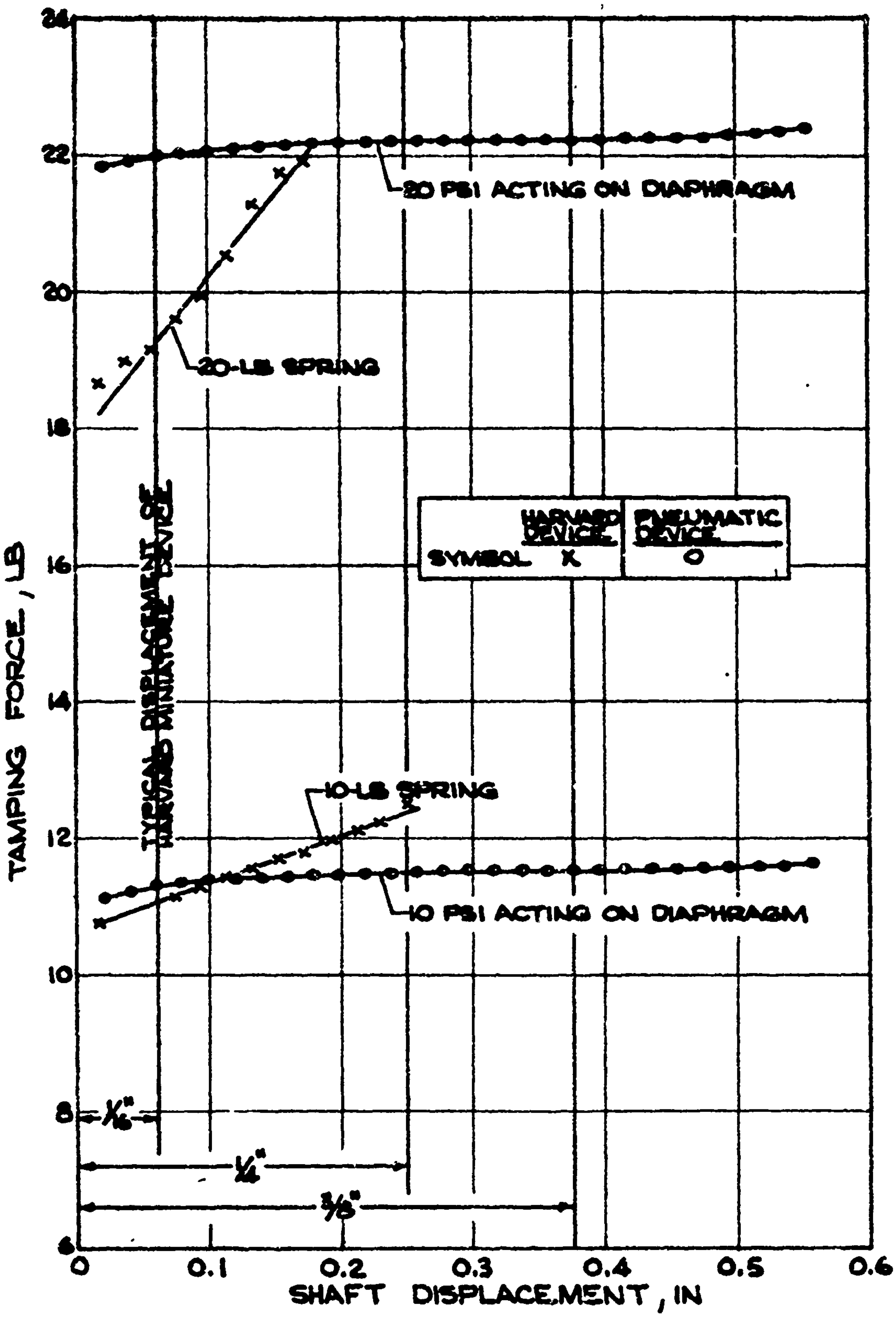


Fig. 7. Force-displacement relationships for Harvard miniature compactor and modified Berkeley pneumatic tamper

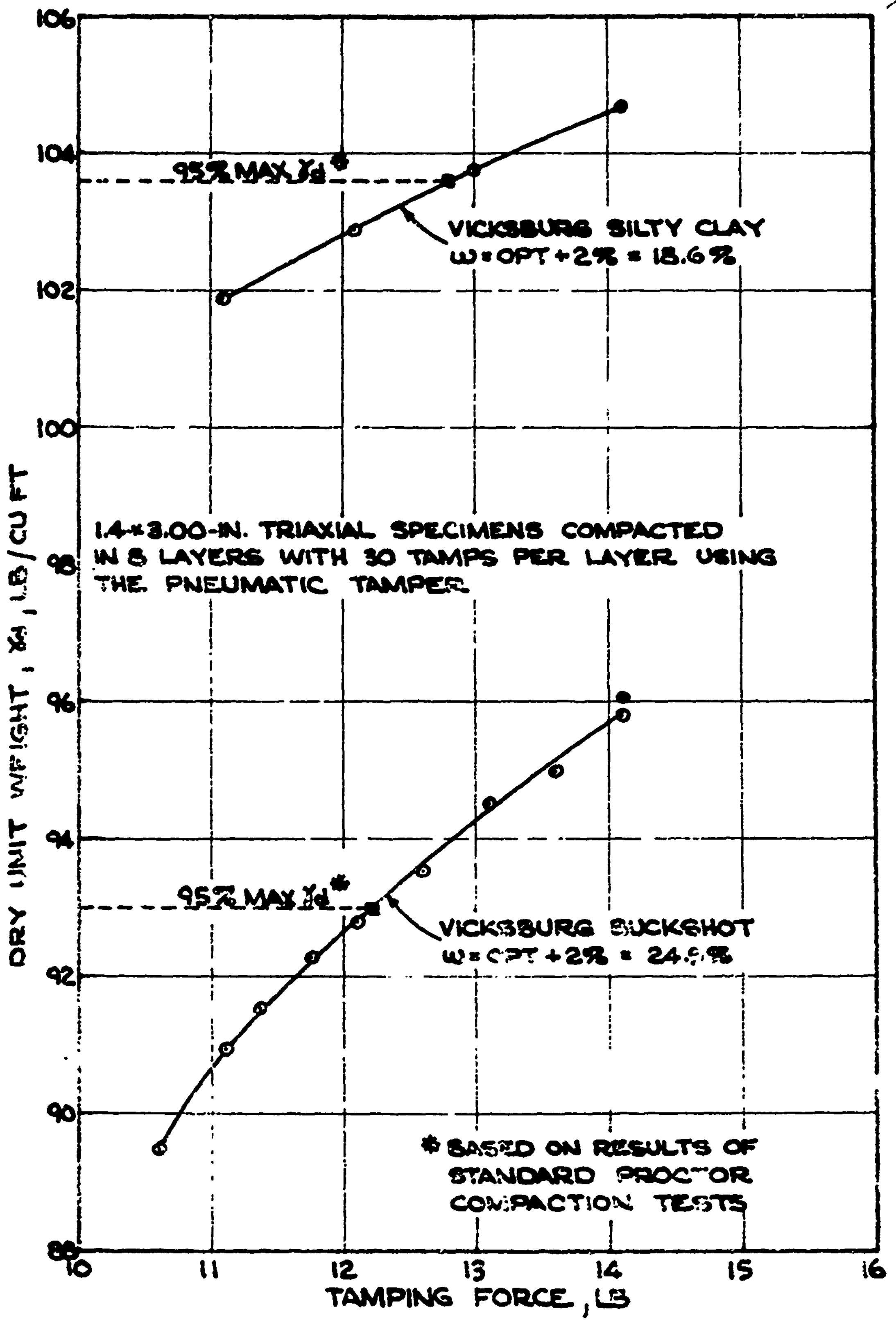


Fig. 8. Relationships between dry unit weight and tamping force for CL and CH standard soil samples

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Fig. 9. Modified Berkeley pneumatic tamper being used to compact a 1.40-in.-diam specimen

1.40-in.-diam triaxial test specimens with 30 tamps per layer. When the first try at obtaining a specific dry unit weight is not successful, a second try is made after a change in the tamping force. With experience, or the development of relationships such as those shown in fig. 8, the change in force will almost completely ensure that the second try will be successful. If a third try is needed. its success is virtually guaranteed. Additional specimens can then be easily produced with a single operation for each specimen. Without the ability to control the tamping force, the number of layers and tamps per layer would have to be adjusted, and success on even the sixth try could not be assured.

23. The pneumatic tamper appears to eliminate much of the influence of the individual operator on the dry unit weight of a specimen. When following the same procedure, different technicians of varying experience have been able to produce very nearly the same dry unit weight in specimens compacted of the same soil using the same number of layers, tamps per layer, and force per tamp. More than the tamper is involved in this accomplishment, of course, for the compacting procedure also includes the preparation of the material, the measuring of the material for each layer, the adjusting of the thickness of each layer, etc. (Details of the compacting procedure being studied under ES 516 will be reported separately; this report is limited to a discussion of the tamper used.) Nevertheless, it is believed that the close reproducibility of dry unit weights would not be possible without the pneumatic tamper.

24. It has also been found that a person who has never compacted a specimen before can reproduce the dry unit weight obtained by the experienced technician after only two or three practice specimens. Again, this would not be possible without close control of the details of the entire procedure.

25. A different application of the pneumatic tamper was its use in preparing 2.80-in.-diam triaxial test specimens of fine sand with very low relative densities (less than 20 percent). The sand was moistened slightly and then compacted in layers within a membrane supported by the forming jacket. A 1.000-in.-diam foot was connected to the shaft

for this purpose. Using the same number of layers, tamps per layer, and force per tamp, the desired wet unit weight of a specimen could be reproduced very closely.

Conclusions and Recommendations

26. The modified Berkeley pneumatic tamper is believed to be a significant improvement over the Harvard miniature compactor for compacting 1.40-in.-diam triaxial test specimens of cohesive soils (with different size feet, it can be used for compacting specimens of other dimensions). It permits rapid and precise adjustment of the tamping force, with assurance that the tamping force actually applied to the soil will not vary among different operators. These features result in (a) fewer specimens having to be compacted to obtain a specified dry unit weight with a soil tested for the first time and (b) less variation in dry unit weight among the several specimens in a triaxial test series.

27. The estimated cost of the pneumatic tamper is $500, which is more than 10 times the cost of the Harvard miniature compactor. However, the long-term savings in technicians' time should readily justify the initial investment. It is believed that any laboratory with a large volume of shear and consolidation testing of compacted cohesive soils would improve the quality and efficiency of specimen preparation by adopting a pneumatic tamper. Division laboratories of the Corps of Engineers are required[5] to compact test specimens using a kneading action, and they should particularly benefit from the advantages of this tamper.

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Appendix A

Parts List and Working Drawings

of Modified Berkeley Pneumatic Tamper

Modified Berkeley Pneumatic Tamper

Parts List

Mark	Number Required	Description
A	1	Body, aluminum
B	1	Head, aluminum
C	1	Handle, aluminum
D	1	Piston, stainless steel
E	1	Diaphragm retaining plate, aluminum
F	1	Shaft, stainless steel "60 Case"
G	1	Extension, brass
H	1	Ball bushing spacer, Teflon
I	2	Ball bushing, Thomson XA-81420-SS
J	2	Ball bearing, SKF No. R7
K	1	Retaining ring, Truarc N5000-87
L	1	Retaining ring, Truarc N5000-86
M	1	Retaining ring, Truarc 5100-27
N	4	Flat head screw, No. 4-48NF, 1-3/4 long, brass
O	1	Filister head screw, No. 6-32NC, 1/4 long, stainless steel
P	1	Rolling diaphragm, Bellofram Part No. 4-125-100
Q	1	Male connector, Imperial No. 68-FL, 1/4 tube to 1/8 NPT
R	1	Compacting foot, teflon

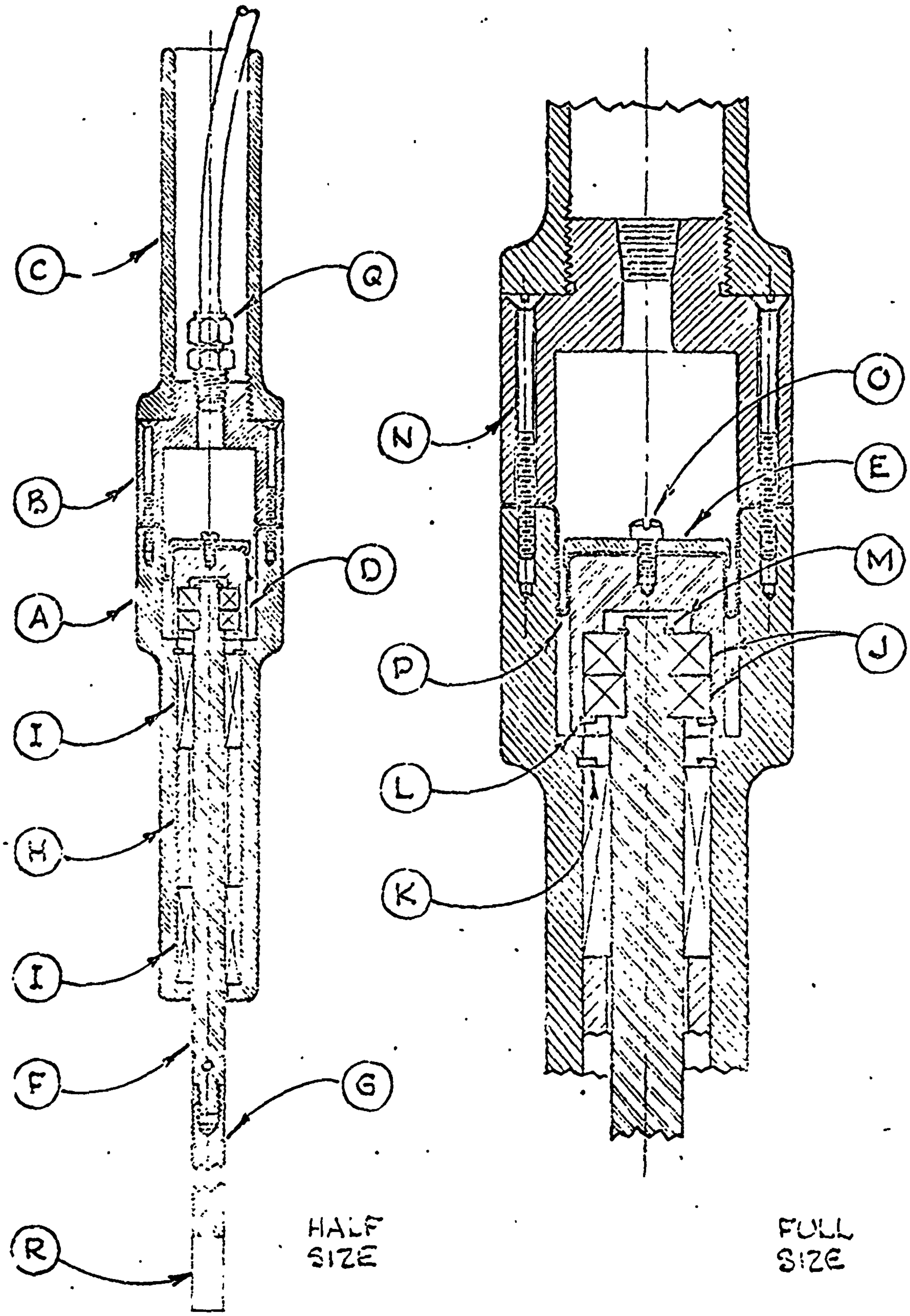


Fig. A1. Modified Berkeley pneumatic tamper assembly

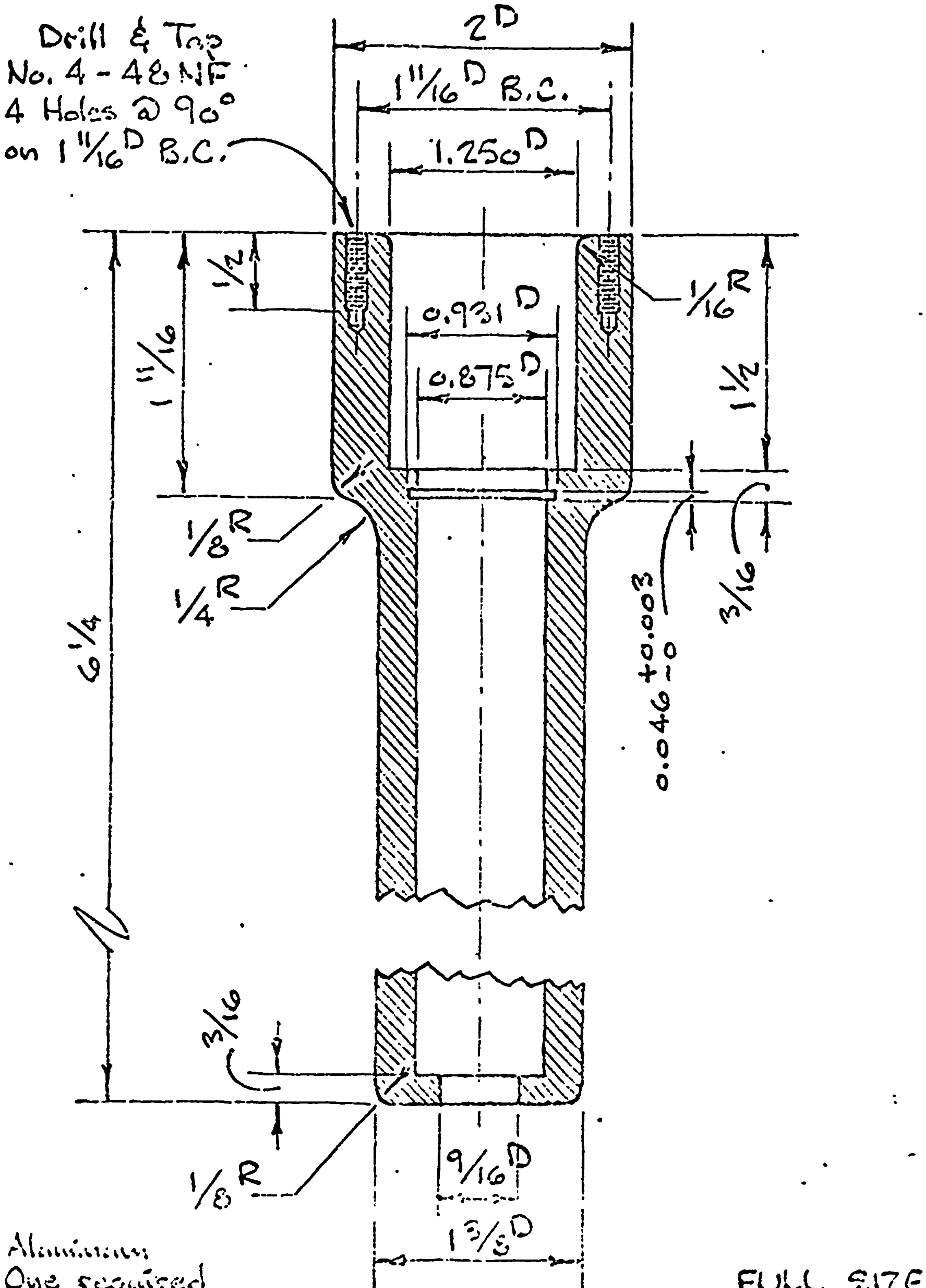
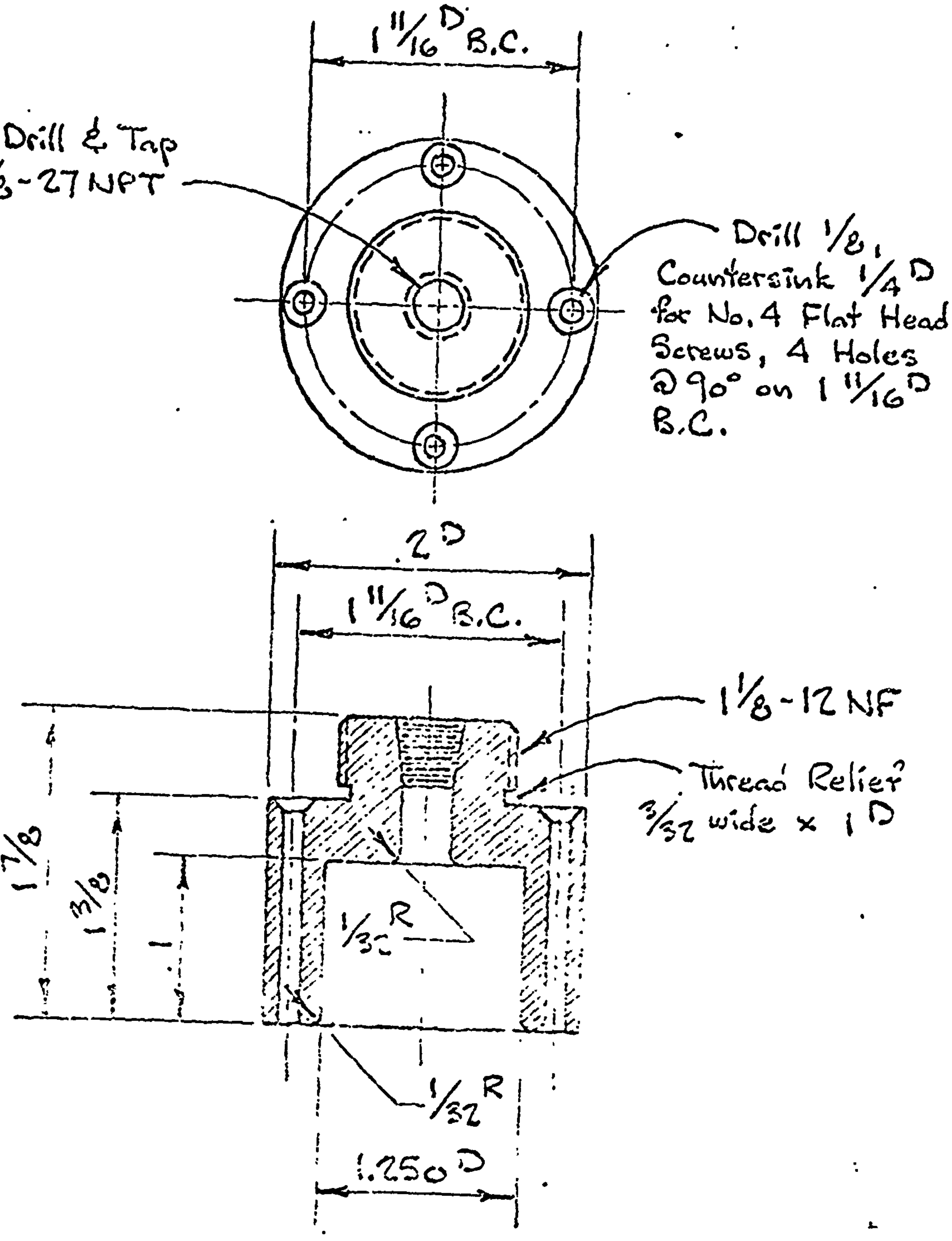


Fig. A2. Modified Berkeley pneumatic tamper body



Aluminum
One required

FULL SIZE

Fig. A3. Modified Berkeley pneumatic tamper head

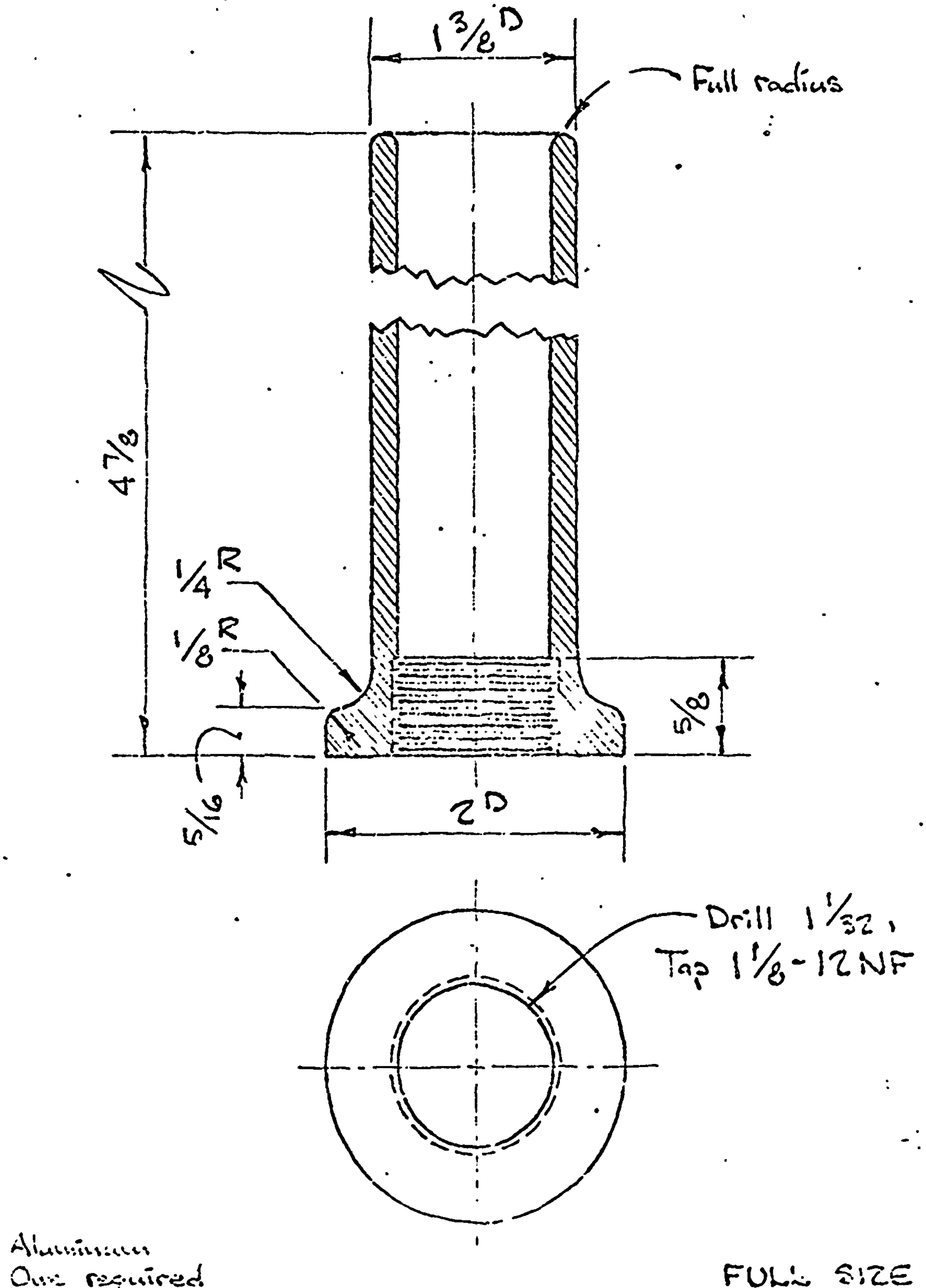


Fig. A4. Modified Berkeley pneumatic tamper handle

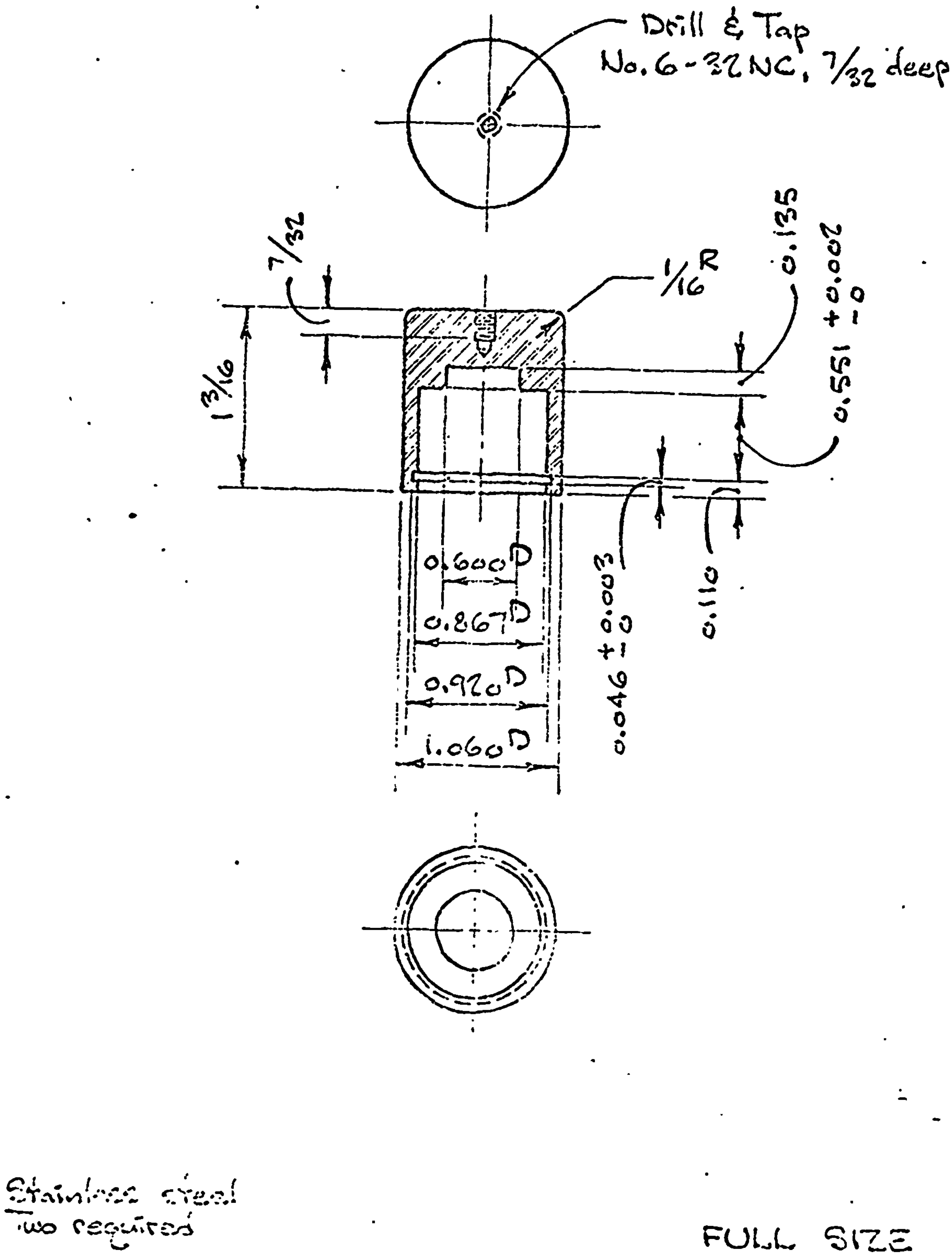
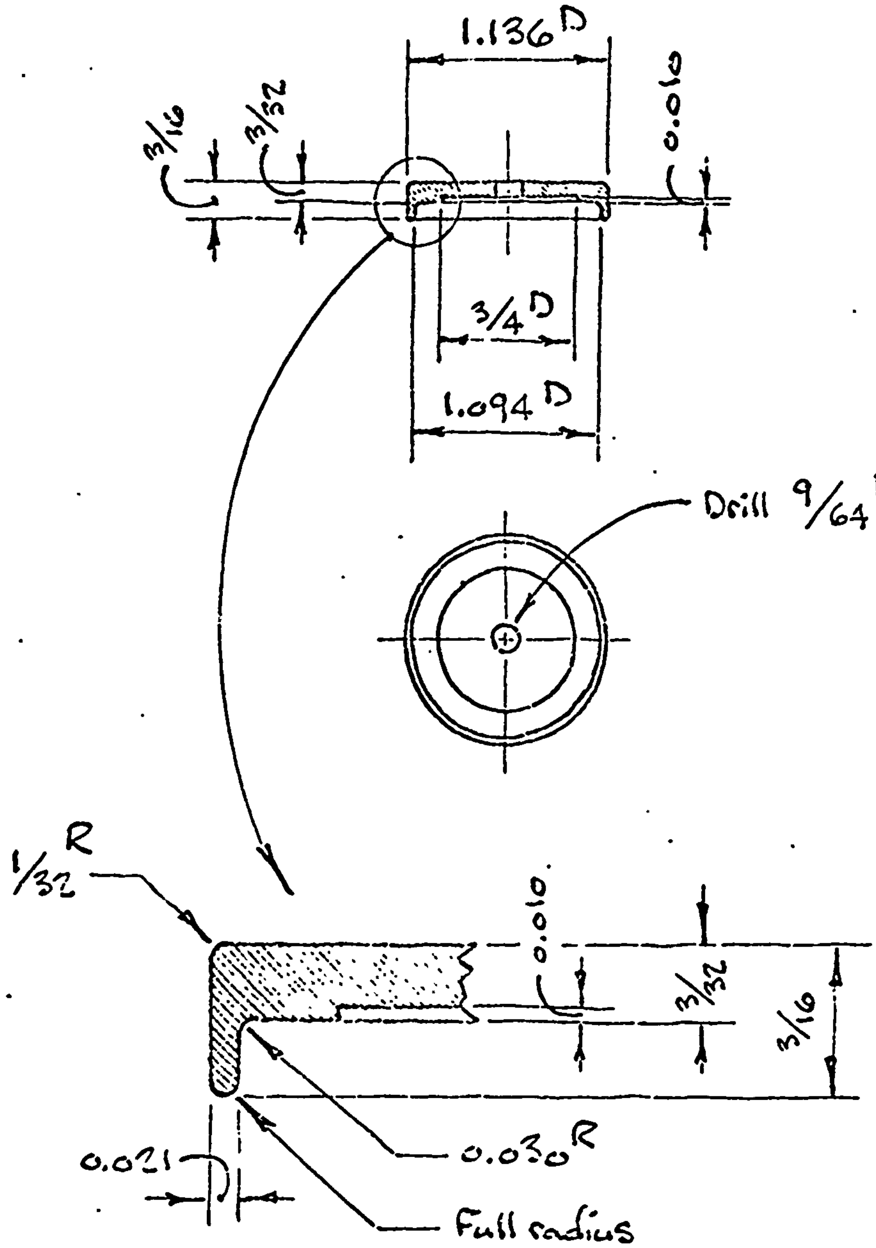


Fig. 45. Modified Berkeley pneumati. tampe- piston



Aluminum
1 required

FULL SIZE

Fig. A6. Modified Berkeley pneumatic tamper diaphragm retainer plate

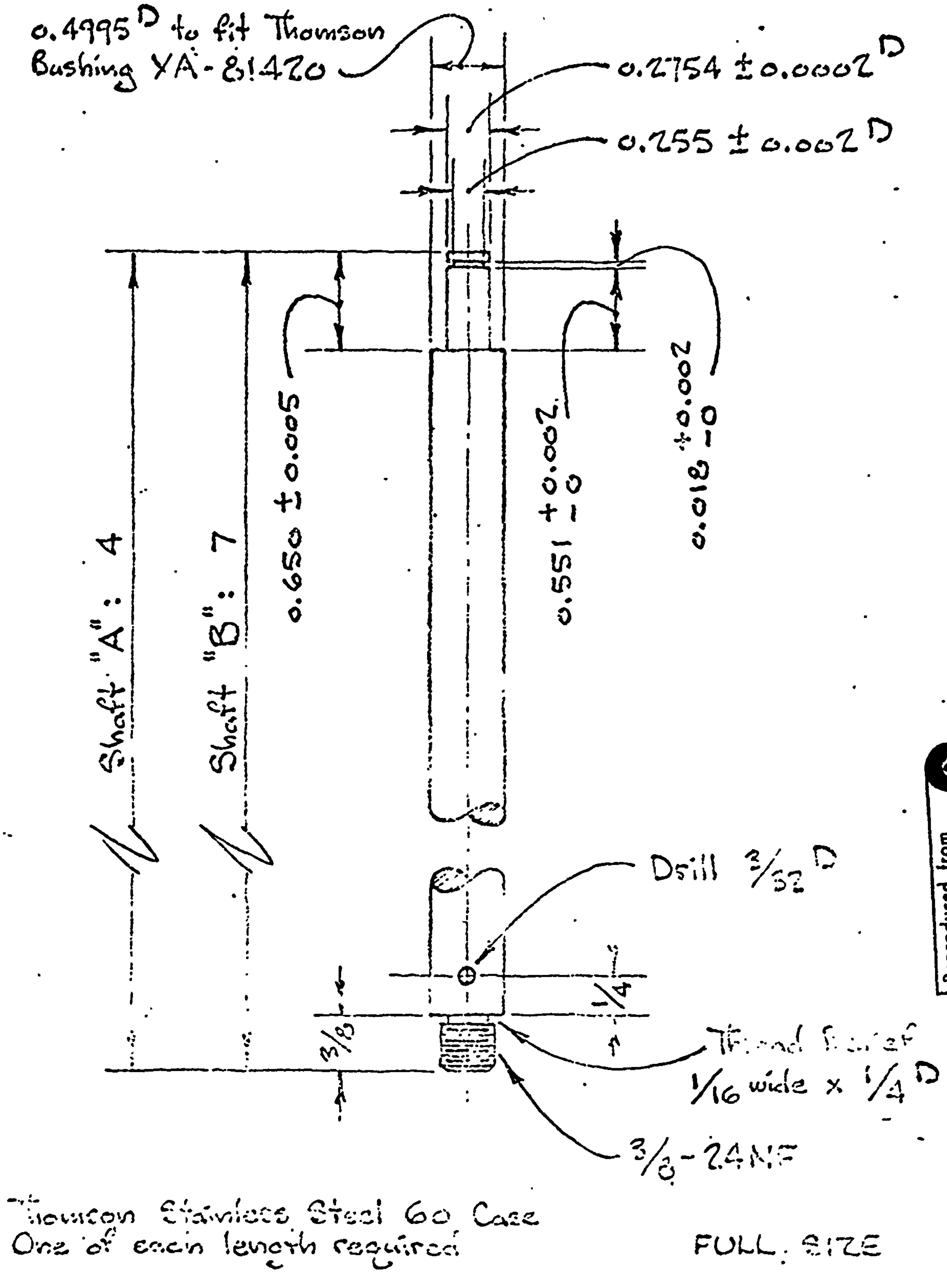
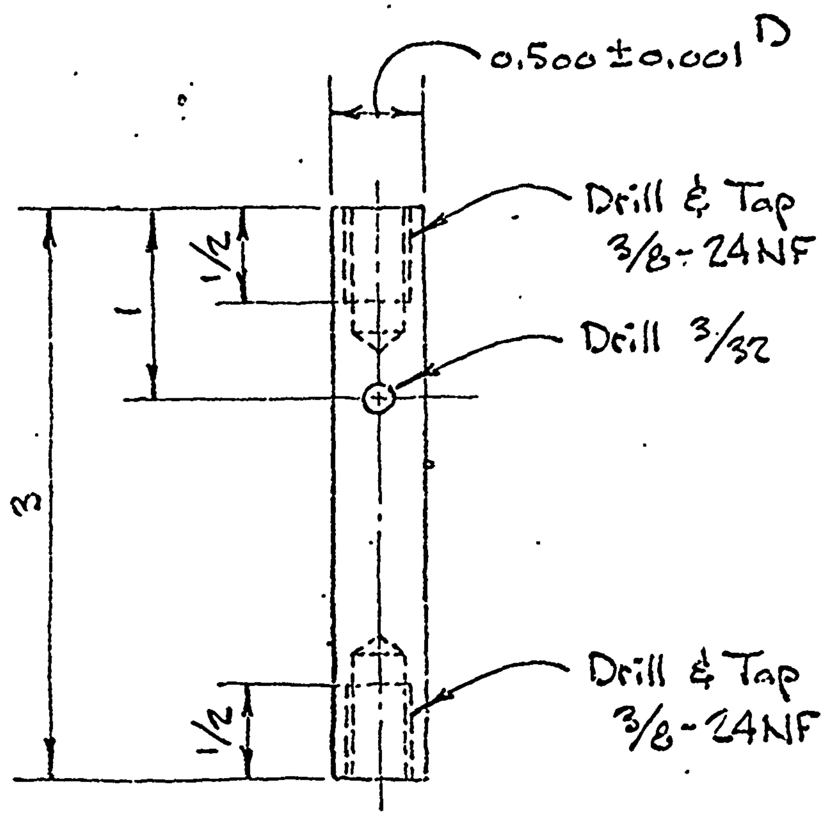


Fig. A7. Modified Berkeley pneumatic tamper shaft



Brass
One required

FULL SIZE

Fig. A8. Modified Berkeley pneumatic tamper extension